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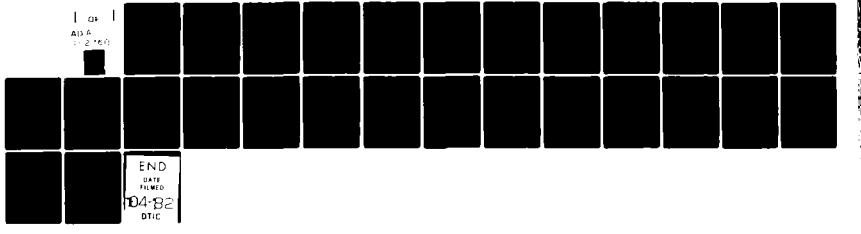

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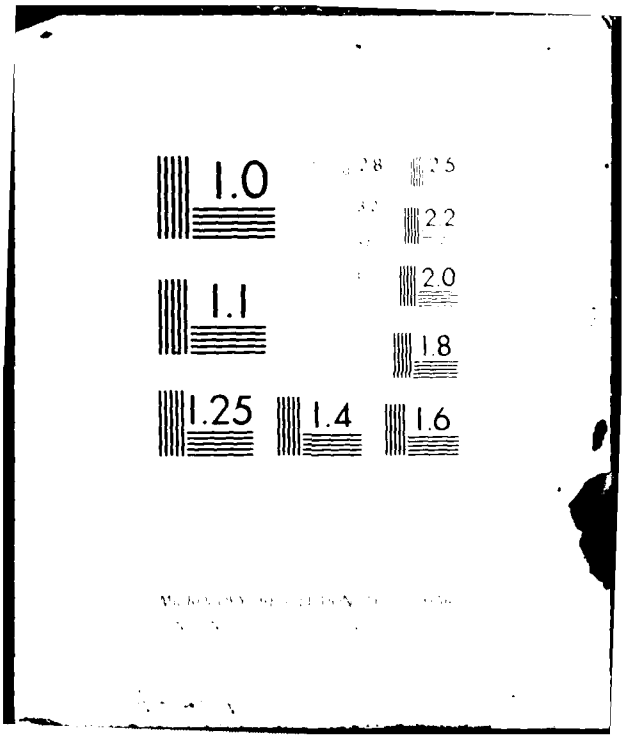
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This report describes the development and operational use of the International Decompression Data Bank (which was established in 1970) at the Institute for Environmental Medicine, University of Pennsylvania with the direct support of the U.S. Navy, in its final phase, under contract N00014-77-C-0090.

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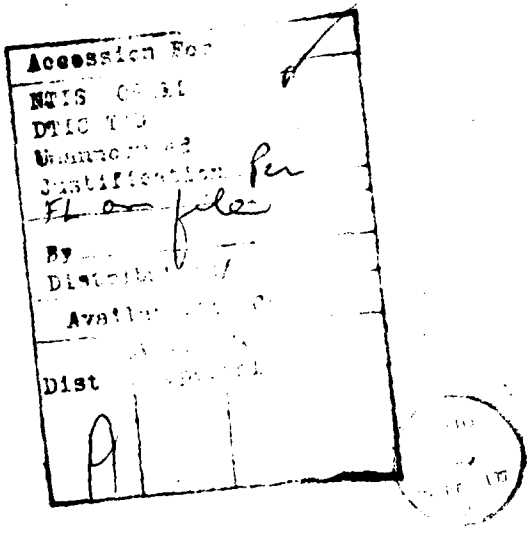
The goal of the Data Bank was to make available to the international community of interested investigators a reliable information service which would provide an open, central repository of validated and systematically recorded experimental results dealing with past and current decompression studies on humans and other animals.

During a ten-year period, the International Decompression Data Bank developed methods for evaluating, recording, storing and retrieving information pertaining to fundamental theory of inert gas exchange, decompression methods and treatment of decompression sickness. Flexible systems were designed to deal with many types of data and to serve many uses. Several commercial diving companies, in addition to concerned federal laboratories and agencies, have expressed strong interest in continued support of the project and use of the (now substantial) data file.



Institute For Environmental Medicine
University of Pennsylvania Medical Center
Philadelphia, PA 19104

DIVING AND AEROSPACE DATA SYSTEM
INTERNATIONAL DECOMPRESSION DATA BANK
FINAL TECHNICAL REPORT

C. J. Lambertsen, M.D.

October 1, 1981

Prepared for the
Office of Naval Research
Arlington, VA 22217

This Technical Report is the Final Report on the Research Project, "Operational Support of Decompression Data Bank" which was conducted at the Institute For Environmental Medicine between November 1976 and September 1977. The research reported here has been jointly funded by the Office of Naval Research and the Naval Medical Research and Development Command through Office of Naval Research Contract N00014-77-C-0090.

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DIVING AND AEROSPACE DATA SYSTEM

INTERNATIONAL DECOMPRESSION DATA BANK

Introduction

As a necessary aid to the evolution of decompression theory, the development of decompression procedures, and the progressive extension of undersea and aerospace activity, it was proposed in 1970 with the U.S. Navy that the Institute for Environmental Medicine establish a continuing system for evaluation, accumulation, storage and ready retrieval of information pertaining to decompression, the development and treatment of decompression sickness and inert gas exchange. Since the phase of development support by the Navy has ended, the accomplishments of the Data Bank project are here documented as a final report.

Background

Inquiries into the practical, physiological and biophysical nature of the decompression phenomenon have entailed considerable financial and personnel investments in this century. The important theoretical model proposed and applied by Haldane, coupling theory with exhaustive testing, permitted investigators to develop pragmatically valuable decompression schedules and tables for divers, safety guidelines for caisson workers, procedures for aviators and astronauts, and schedules for the treatment of bends. As man proceeded to dive deeper and longer, the inadequacy of current techniques for calculating decompression schedules for these extended exposures became obvious.

The development and validation of decompression theory was seriously hampered by the absence of an adequate and available fund of information. This deficit was due in part to the difficulty, time and expense of decompression studies, such that no one investigator or laboratory could conceivably generate sufficient data to directly test and validate the current concepts of decompression theory, and in part, to the infrequent publication of the data obtained from decompression studies in the open literature. This failure to make data immediately and fully available, whether from commercial or national interests or because of the specifically applied nature of the studies, is a rare phenomenon in the biomedical sciences and served to impede the progress of all concerned.

In addition the decompression data collected on man over the last several decades were disappearing. Where experimental protocols and log books have been retained, their contents are not available in any generally useful form and many associated and important facts are being lost or forgotten. As new types of decompression experiments were performed and then not published

in detail, their data too rapidly enter this large pool of unretrievable information.

Establishment of International Decompression Data Bank

To prevent the further loss of valuable decompression data and to provide hyperbaric research laboratories full access to all existing decompression data of high quality, the International Decompression Data Bank was established. The primary purposes of this Bank were:

1) To make available to the international community of both government and civilian investigators a reliable information service which provides an open, central repository of validated experimental results dealing with past and current decompression studies;

2) To systematize the methods of observing and of recording decompression studies so that all critical information is retained, and so that studies performed by any organization may be understood by all;

3) To provide a versatile system capable of storing a variety of experimental records, analysing theoretical models and designing decompression tables;

4) To protect against the loss of significant information;

5) To generally encourage and assist the improvement of decompression safety and efficiency throughout the world.

Special assets of the Institute made it a rational choice as the site for the Data Bank, including:

An advanced environmental medical laboratory system for undersea and aerospace studies. The existance of these laboratories assures that interest in gas exchange, diving, decompression, bends therapy and altitude exposure will continue indefinitely.

A computer system within the Institute which now provides storage and retrieval capability and, in addition, computation and graphics software for analysis.

A major computer center affiliated with the University has a system configuration reflecting the state of the art in computation.

The Data Bank was originally designed to serve military and civilian government, university and commercial investigators for the advancement of decompression theory and practice. A Scientific Advisory Board, composed of established investigators from

throughout the world, helped establish Data Bank policies and procedures and provided continuing guidance. A Task Group developed the Data Bank systems and operated the Bank on a day-to-day basis.

Relevant information about both high and low pressure exposures, including exposure profiles, subject information and the published results of any biomedical studies was acquired and entered into both hard copy and computer storage systems. Portions of the data, the exposure records and extracted summary information about each exposure, were to be part of a large computer software system which would allow for the retrieval of dive records meeting criteria specified by a Bank user. A computer software system allowed user requested analyses to be performed on the dive records.

Data was obtained from reputable research laboratories. After being encoded into a form which could be read by both a Bank user and the computer system, it would be entered into the Bank. The encoding process was designed to serve as a quality control mechanism by insuring that all information required to present the exposure in an accurate, complete and unambiguous form was present. If an exposure record was not entirely acceptable, the information necessary to make it so was to be obtained through the originating laboratory or the exposure was to be rejected for entry into the Bank.

Organization

The Scientific Advisory Board was established to provide overall policy guidance and to ensure that the information included in the Data Bank would be of high quality. The following international leaders in decompression research served on this board during the developmental period:

Dr. Christian J. Lambertsen - U.S.A., Coordinator
Dr. Kenneth N. Ackles - Canada
Dr. Albert A. Buhlmann - Switzerland
Dr. Jacques Chouteau - France
Dr. H.V. Hempleman - England
Dr. Carl Magnus Hesser - Sweden
Dr. Ichiro Nashimoto - Japan

The Data Bank Task Group was composed of members of the staff of the Institute for Environmental Medicine at the University of Pennsylvania. This group was responsible for 1) development of computer systems for storage and retrieval of the data bank information, 2) transcription, coding and data entry of the material judged adequate for the bank, 3) processing of requests for information from the bank and 4) management functions required for the smooth operation of the project. Cdr. Claude Harvey, MC, USN, and Russell E. Peterson, Ph.D., served as co-ordinator of the Task Group during the contract period.

The initial phase of development and consolidation is now complete. In the 10-year period, many thousand experimental exposure records have been received, transcribed and stored by the data bank and used in research, development and safety programs of this Institute, and other universities and organizations. The Data Bank has provided information and analyses to many users. Representative projects which have received support and assistance from the Data Bank are listed below.

Modification of Tektite decompression system to eliminate limb bends and formation of bubbles in vitreous of eye. For U.S. Department of Interior.

Derivation of decompression systems for Flare and Hydrolab nitrogen-oxygen saturation programs. For NOAA.

Analytical assistance for open sea, nitrogen-oxygen saturation-excursion operations. For NOAA-PRINUL.

Development of decompression system for 100 FSW saturation exposures. Extension of exceptional exposure tables for nitrogen-oxygen breathing. For ONR and Interior Department.

Development of guidelines for flying after nitrogen saturation diving in relation to NOAA field operations.

Assistance in analysis and development of decompression and deep bends treatment procedure for nitrogen-oxygen saturation-excursion diving program. For NOAA and U.S. Navy.

Providing information on decompression from deep, non-saturation helium-oxygen exposures. For Canadian Defense and Civil Institute for Environmental Medicine.

Provision of information on altitude decompression. For Scripps Institute, NASA, and U.S. Navy.

Development of decompression methods to be used for helium-oxygen diving in the 350-650 ft. range and for use from lock-out submersibles. For Harbor Branch Foundation and Duke University School of Medicine.

Data on N_2, He and Ar exposures of rhesus monkeys has been provided to Naval Submarine Medical Research Laboratory at New London.

Provision of rhesus monkey decompression information. For Canadian Defense and Civil Institute for Environmental Medicine and University of Toronto.

Provision of information used in the determination of parameters for calculation of decompression schedules by the U.S. Navy Experimental Diving Unit for a) the development of

new repetitive diving techniques for air exposures to 200 fsw; and b) development of decompression tables for non-saturation oxygen diving in the 380 to 420 fsw depth range for application to the ADS IV diving system.

Played an important role in the development and documentation of the decompression procedures used for the deep helium excursions (1600 fsw) made during the Predictive Studies IV at the Institute for Environmental Medicine.

Current Status and Future Plans

The expanding character of underwater and aerospace operations now makes it necessary to consider extending the scope to include operational retrieval and storage of relevant information concerning (a) tolerance to oxygen toxicity, (b) decompression sickness and (c) therapy of decompression sicknesses generated in any form of diving or aerospace activity, and in tunneling work. Since Navy support will now be discontinued and since the University is not itself able to provide the financial backing for industrial or government use of this activity, support will now be sought from other government and industrial users. Custodial care and development of new applications and functions will be provided by Ecosystems Technical Transfer System, a Pennsylvania corporation adjunct to the Institute for Environmental Medicine and the University of Pennsylvania. In accordance with its design by University management and research staff, Ecosystems provides a mechanism for the transfer of technical information and has access to professional and technical staff members of universities.

Present plans will extend the scope and functions to allow a Diving and Aerospace Data System to evolve with:

1) Continuing accumulation of international diving information with retrieval, analysis and storage for improvement of safety in acute and long term decompression, isobaric counter-diffusion and pressure exposures to protect against permanent loss of significant technical information.

2) Extension to include analysis and storage of information concerning the acute and chronic effects of oxygen toxicity (which represents ultimate limits both in diving safety and in treatment of decompression accidents).

3) Correlated storage of decompression and isobaric accident and therapy procedures, to provide for improvement in treatment of diving accidents involving the several gas lesion diseases.

GENERAL POLICIES OF THE DIVING AND AEROSPACE DATA SYSTEM

Data Format and Acceptability

The Data System will continue to receive complete, accurate recordings or plans involving either laboratory or operational pressure exposures. The purpose of the exposure (whether research, sport, federal or commercial) is not critical. Experimental, working and recreational exposures can be included, as long as the diving or treatment profile, gases breathed, adjunct therapy and other facts about the exposure or therapy are accurately known.

The initial responsibility for the accuracy and completeness of the information lies with the contributing organization or source. All data received will be reviewed under definitive guidelines to assure the quality of material included in the Data System records. If serious questions as to accuracy or gaps in information appear and cannot be resolved, the data will be filed but will not be entered fully into the Data System.

Exposures recorded in a language other than English will be translated into written English prior to computer storage.

Diver, Subject or Patient Identification

It is the policy of the Data System to uniquely identify indi- vidual subjects or divers and not to divulge their names, since the identification of a subject by name could, under some circumstances, endanger his livlihood or cause embarassment to his agency, company or laboratory. However, to allow for the correlation of data, the identification of an individual in an exposure submitted to the Data System should be explicit enough (either his full name, his Data System identification, if he already has been assigned one, or a unique company or laboratory identification number) so that an individual may be identified even if he appears in numerous exposures.

Proprietary Rights

All information in the System will be open unless a particular agency or unit designates specific information as proprietary. It is expected that, if a substantial amount of data from one source is used by another in the development of decompression schedules or allowable supersaturation parameters, the original source will be given just credit for its contribution to the effort.

Types of Information

The specific effects and the types of exposure which provide information about them to be included in this expanded data system are:

Oxygen Effects. Physiological and toxic effects of oxygen upon man represent the major limiting factors in improvement of diving safety, decompression, and decompression sickness therapy. Systematic documentation of conditions and effects in controlled investigations of human exposure to oxygen poisoning provides the continuing basis for improvements in hyperoxic therapy of both decompression and isobaric counterdiffusion gas lesion diseases, and for decreasing acute or chronic consequences of exposure to toxic pressures of oxygen itself in diving and in therapy. Information obtained and systematically maintained for analysis includes damaging effects of oxygen at various pressures upon respiratory, pulmonary, visual, hepatic, renal, exercise, cardiovascular, central nervous system and endocrine functions.

Compression Rate Effects. Rapid compression modifies not only nervous system functions but also the alveolar, arterial and central nervous system pressures of oxygen, carbon dioxide and inert gases. Acquisition of validated information on functional, symptomatic and gas changes associated with different rates of rapid compression of men will permit correlation among different studies from different laboratories.

Effects of Saturation Exposures. Continuous lengthy exposure to high pressures of nitrogen, helium, neon or mixtures of these or other inert gases induces specific effects upon numerous physiological systems and functions, in some instances to a severe, hazardous and incapacitating degree. Information concerning these effects in man will aid in developing operational safety guidelines.

Decompression Effects. Numerous decompression systems exist and continue to be developed empirically for diving, aerospace, caisson and tunnel work. It is proposed to maintain and extend the validated documentation of controlled studies of decompression following (a) excursion from the surface with various respiratory gases, (b) excursion from saturation at high pressures, (c) saturation with different inert respiratory gases (e.g. helium, nitrogen, neon, nitrogen/helium). Cross correlations will provide information necessary for determination of factors in the generation of forms of decompression sickness and for improvement of theory and in safety of decompression practices.

Isobaric Inert Gas Counterdiffusion Exposures. It is now known that even at constant pressure (isobaric state) forms of gas lesion disease can be generated by exposures which produce "superficial" and "deep tissue" isobaric inert gas counterdiffusion. No systematic documentation of isobaric counterdiffusion

exposures has been carried out, in spite of the incapacitating and lethal potential. Systematic documentation of isobaric inert gas counterdiffusion exposures in man at various pressures will allow determination of (a) isobaric hazard, (b) the inevitable interaction of decompression sickness and both the "superficial" and "deep tissue" forms of isobaric counterdiffusion, and (c) the adverse and beneficial influence of isobaric counterdiffusion in the treatment of gas lesion diseases of diving.

DATA STORAGE AND PRESERVATION

Information preservation under this system is accomplished by several procedures, depending upon the specific character of the information stored and the specific requirements for retrieval. Specifically designed recording and storage systems will be required for each of the several related components of the information and data system. The format and content of each category of information recording must be compatible to facilitate subsequent analysis and correlation. However, it may be desirable to develop coding and entry procedures to fit different kinds of data.

Types of data will include (a) diving and other operation records (including circumstances, diving and decompression profiles, participants, equipment, etc.), (b) decompression experiment records, (c) medical examination records, (d) decompression accident, medical and treatment records, (e) oxygen tolerance study records. As currently organized the data storage is categorized in these files:

1) Decompression Methods File

This comprises operational, developmental and theoretically based decompression procedures/tables for use with various respirable inert gases, multiple mixtures, sequences and oxygen dilution, provided by agencies and laboratories of different countries. Files now include excursion, saturation-excursion, and saturation decompression procedures, concepts and experiment information relating to continuing evolution of decompression procedure. The majority of files is in hard copy, organized for comparative analysis, with computer storage of coded features proposed.

2) Laboratory Decompression/Oxygen Tolerance Experiment Data File

This comprises accumulating validated series of controlled, precisely documented and non-standard pressure/gas exposures, representing basic information standards against which decompression method development programs and tables can be calibrated. Storage is by hard copy and by computer storage of gas exchange/oxygen exposure analyses.

3) Diving Operations Information File

This file system encompasses records of circumstances of open water, working diving activity, as provided by collaborating federal agencies, scientific, commercial or other organizations. Storage is by computer, both disc and tape. Appendix C describes an example of this type of system.

4) Diving Accident Record System File

This system provides for preservation and coded organization of circumstances of sport, scientific and other diving accidents, including fatalities. Because of the infinitely diverse character of information, storage is by detailed case history, together with the special, pertinent "Key Word" Index which allows systematic retrieval of organized information. This File provides the basis for preservation of information concerning circumstances of fatality or accident, whether traumatic or pressure/oxygen related. It does not directly encompass detailed therapeutic procedures but is correlated with the Therapy File.

5) Therapy File - Decompression Sickness, Gas Embolism, Isobaric Counterdiffusion Sickness

This system, correlated with "Diving Information" and "Diving Accident" systems, preserves for analysis the extensively varied procedures, therapeutic measures and adjunctive methods, and results of treatment in the several different gas lesion diseases. Preservation is necessarily by case history (computer stored) and also by hard copy of initial reports.

RETRIEVAL, ANALYSIS AND REPORTING

The development of this central repository for the cited forms of diving, decompression, oxygen tolerance, accident, and therapy information gives diving and aerospace laboratories and qualified individuals access to the past experience upon which design of improved methods and safety features are necessarily based. Current design provides that data may be retrieved by specific technical features (depth, gases, type of diving, oxygen exposures), by date, by geographic location, by individual diver or subject or other pre-planned focus. As required, computer search is backed by full detail from hard copy primary records. Requests may be made for specific data, full case histories or mathematical, statistical and graphic analysis. Report formats will continue to be developed to meet the needs of different purposes and users (commercial, military, aerospace, scientific).

COMPUTER FACILITIES

Assets available to the Diving and Aerospace Data System include the computer facilities of the Institute for Environmental Medicine and access to other computer facilities of the

University of Pennsylvania, with their supporting software, and especially designed programs and software systems.

IFEM hardware facilities include:

PDP-11 Computer System adapted for multiple terminals, time-sharing:

Computer Memory of 96K (32K of Core, 64 of MOS)
Multiplexer - eight line
Modem (Planned, for telephone access)
Versatec Matrix Printer Plotter
Digital Graphics Terminal, with light pen
RK-05 Disc Drives (three, 1.2 megabytes)
RK-07 Disc Drives (25 megabytes)
Magnetic Tape Drive
Diablo Letter Quality Printer (Computer/Word Processor)
Terminals (3 VT-100, One DEC-Writer)(2 Teletypes)

Vector Graphics

M/Z Microcomputers (three for use in data input)
Floppy Disc Drives (two each)
Graphics Terminal (each)
Share one Line Printer

Laboratory Peripheral System

Eight channel analog to digital converter

Other local computer installations which could provide additional capability if required are:

University of Pennsylvania Medical Center - DEC-10 System
University City Science Center (Unicol) - IBM 360 and 370 systems

IFEM Software

Computer programs for analysis or comparison of diving decompression procedures, oxygen exposures in diving decompression and therapy, and prediction of superficial and deep tissue isobaric counterdiffusion hazard are available and under continuing development (Appendix A).

A general purpose data base system has been developed at IFEM which incorporates programs providing storage, search and retrieval mechanisms for varied data storage requirements (Appendix B).

A Diving Information Management System (DIMS) for handling open-sea diving records which utilizes the IFEM data base system has been established under the Technical Transfer Center and is

now in use. Computer assisted coding and verification programs provide the mechanism for data entry. A coding manual has been written which allows non-technical personnel to accomplish data entry. Appendix C describes schematically how the DIMS functions and lists the information fields available for search.

LONG RANGE OBJECTIVES

It is generally recognized that the United States, as well as most nations of the world, will look to the ocean floor for future sources of energy, minerals, and food. Actually a considerable amount of energy is presently available only by exploitation of subsea reserves of oil. It is further recognized that future exploration of the deep ocean floor will be conducted by completely mechanized systems. Until development of total mechanization, however, the diver will remain a crucial element in the ocean resource extraction process. Man will therefore be subjected to deeper depths and in greater numbers in the foreseeable future. This situation requires that advances be continually achieved in diver safety. An organized documentation system could play a significant role in this progress.

It is planned to explore the possibility of private industry utilizing an automated record keeping system for documentation of operational safety in underwater activity. In addition to the documentation function, this would provide the data necessary for analyzing the safety and efficiency of diving tables and decompression procedures.

Selected Software Available to Diving and Aerospace Data system

Diving and Decompression-Related Programs

Program Name	Features	Medium
DIVCAL	Major Diving Decompression and Oxygen Tolerance Program Computes, for fixed and for variable time-depth-gas profiles, the predicted gas uptake and elimination for a maximum of 20 mathematical tissue compartments, three inert gases and fully variable oxygen pressures. Provides composite of tissue inert gas saturations and cumulative pulmonary oxygen toxicity. Tissue gas partial pressures specified by names, with changes in pressure before and after each pressure or gas change. Provides for computation of excursion or saturation decompression. Permits continuous variation of respiratory gases in breathing mitxure over a number of depth changes. Provides computation of "deep tissue" isobaric supersaturation and subsaturation concurrent with steps in decompression gas exchange.	Tape, Disc
PENNDEC	Dive Recording Input Penndec Coded Data Output dive profiles	Cards
IDDBO2	Reads Penndec Program	Cards
MERMAID	Converts coded dive to readable printout	Cards
PADUA	Predicts changes in tissue inert gas and oxygen with multiple and sequential inert gases, completely variable pressure and oxygen profiles. Diving, pressure and altitude.	Cards, Tape, Disc

PADUA NU	Improved output format for PADUA, including time between stops.	Tape, Disc
OPTUS	Program for optimization of pressure exposure among decompression, narcosis and oxygen toxicity variables. Print-out of optimized decompression tables.	Cards
UPTD	Computes cumulative pulmonary oxygen toxicity in continuously variable oxygen exposures of diving, decom-pression and therapy.	Tape, Disc

Other Software Packages and Programs

IFEM Data Base system - A library of interactive Fortran programs which allow files to be created, edited, displayed, searched, sorted and merged. See description in Appendix B.

BMDP - Statistical analysis programs designed for use with biomedical data.

Graphics Programs - Provide plotting capability on graphics terminal and printer plotter.

MASS-11 - Data Base Management and Word Processing Package.

APPENDIX B

Reprinted from PROCEEDINGS OF THE FOURTH ANNUAL SYMPOSIUM
ON COMPUTER APPLICATIONS IN MEDICAL CARE, November 1980

THE INSTITUTE FOR ENVIRONMENTAL MEDICINE DATA BASE SYSTEM

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The Institute for Environmental Medicine Data Base System (IFEMDBS) allows the non-computer oriented researcher to set up and manipulate a biomedical data base. The IFEMDBS interactive Fortran programs interpret between user and data file, allowing files to be created, edited, displayed, searched, sorted or merged. A library of subroutines facilitates programming for unusual applications.

An IFEMDBS record is defined by a Data Definition File (DDF). The DDF contains a Fortran format to control record I/O and gives specific information about each field.

A sample biomedical data base is discussed, including benchmark results showing how different file manipulation procedures are affected by the file characteristics.

The Institute for Environmental Medicine Data Base System (IFEMDBS) is specifically designed for the input, storage, organization and directed retrieval of biomedical data. It is written in Fortran-IV for the PDP-11/40 running under RT-11 and allows file organization of a wide variety of data records. The files are standard ascii files and can be accessed by all of the appropriate file maintenance facilities of the RT-11 operating system. They are compatible with user-written Fortran programs, and can be used as data files for the BMDP statistical programs.

The IFEMDBS is composed of two related software packages; one designed for the day-to-day user, and one for the programmer. The user's package is a series of nine interactive programs which allows data files to be created, edited, displayed, searched, sorted, merged, or rearranged. The programmer's package is the IFEMDBS subroutine library which allows specialized programming to be accomplished quickly and painlessly, and without regard for the storage structure of the records.

OVERVIEW

An IFEMDBS data file is a sequential collection of records with a common logical structure. This structure is defined by a specialized file called a Data Definition File (DDF). The IFEMDBS programs depend on the DDF to supply the structural information necessary for correct record interpretation. An IFEMDBS file can contain records of only one data structure, and every structure must be defined by a DDF.

A DDF defines an IFEMDBS record as having a fixed number of fields, each containing a maximum number of entries. A field has a label and a type, which is the same for all entries in that field.

A greatly simplified version of one of the biomedical data bases set up at the Institute for Environmental Medicine will be used to illustrate a basic data file structure. In this data base, each record contains complete information on a single experiment. The experiments were designed to investigate the relationship between the partial pressure of oxygen in the breathing gas mixture and the heart rate in rats. The following information was collected: experiment ID; rat ID; date of experiment; treatment; physical condition at the end of the experiment; and the heart rate measured every hour for 12 hours, or until the death of the animal. One possible structure for these records is shown in Figure 1.

FIGURE 1

FIELD NUMBER	FIELD NAME	TYPE	MAXIMUM ENTRIES	FORMAT TYPE
1	Experiment ID	Integer	1	I5
2	Rat ID	Integer	1	I5
3	Day	Integer	1	I2
4	Month	Integer	1	I2
5	Year	Integer	1	I4
6	Treatment Code	Ascii	3	3A2
7	Rat Condition	Ascii	1	A2
8	Heart Rate	Integer	12	12I4

Total Number of Fields: 8
Total Number of Entries: 21

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Experiment ID, rat ID, day, month, and year are set up as integer fields with only one entry allowed. Up to three double character alpha-numeric treatment codes, and one to describe the rat's condition, can be stored. The heart rate field has a maximum of 12 entries, allowing for a full 12 hours of data points.

File names are given under the conventions of the operating system. We are running under RT-11, and might choose to call the master experimental file MASTER.RAT. This file can be manipulated using any of the IFEMDBS programs. A file called TREATA.RAT can be created of all rats which received treatment code AA as one of the three treatments, or HIHRT.RAT of all rats which achieved a heart rate beyond the normal ranges. The records in these files will share a common structure and will be defined by a single Data Definition File (DDF).

THE DATA DEFINITION FILE

The IFEMDBS is customized to a particular application by the creation of a data definition file . The DDF must contain the information necessary for the IFEMDBS programs to read and write the records and to be able to interpret the fields. The DDF is straightforward. It can be created manually using any text editor or by using the specialized program DBCRT. DBCRT queries the user about the desired data structure and translates this information into a DDF with the proper format. Before running DBCRT, the user must decide on certain record characteristics including the total number of fields, and the individual field assignments for label, type, entry length, maximum number of allowable entries, and "null values." Finally a Fortran format is written to control record I/O.

The first of these characteristics, the label, is any combination of up to 20 characters. The IFEMDBS programs use the label when referencing that field. It should be a name that will be meaningful to the user.

The field type can be one of three possibilities: Ascii, Integer, or List. An ascii field can contain one or two ascii characters. An integer field can contain any valid integer number within the limits of the computer. A list field contains a string of ascii characters. A real number field can also be created as a special case of the list field, which would allow only the sign, number, and decimal characters.

The field length shows how many characters long each entry is. Ascii fields can be single or double characters with length 1 or 2. Integer fields can contain up to 6 characters including a sign, although most of the 5 digit numbers are invalid integers for 16 bit computers. Each entry in a list field can be up to 99 characters long.

Fields are allowed to have any number of entries, but the total number of entries cannot exceed 999. For purposes of this calculation, each character in a list field requires one entry. Thus a list field with a maximum of 4 entries, each 10 characters long would use 40 of these 999 entries.

Finally, each field gets a null value. A field is assigned physical space on the basis of the maximum number of entries it can have. The unused portion of the field is filled with the null value. The null value is an entry which would never occur as an actual value. For integer fields, it can be any valid integer within the number of characters defined in the length. For ascii fields, it is one or two characters. For list fields, it is a single ascii character which gets propagated throughout the unused segment of that field.

The Fortran format entered into the DDF is the actual I/O format used to move records between files. The format follows standard Fortran rules, using an A1 or A2 descriptor for ascii fields, an I descriptor for integer fields, and an A1 descriptor for list fields. A DDF that would describe the oxygen toxicity data records is shown in Figure 2.

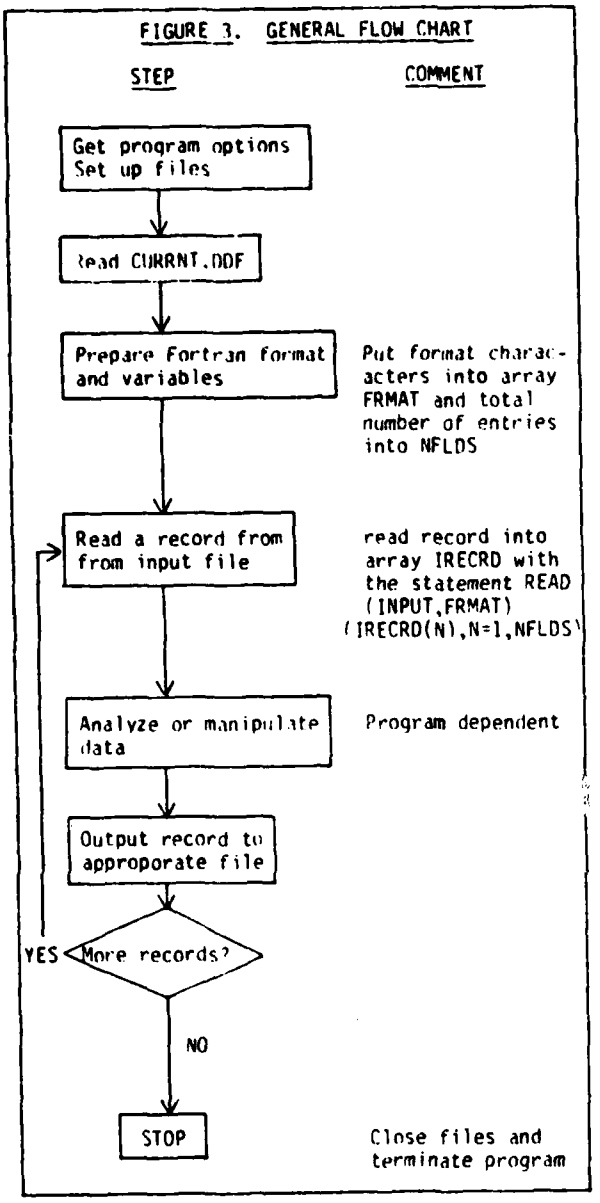
FIGURE 2. RAT.DDF

```
Rat Experiment DDF
021 Entries
008 Fields

(I5,I5,I2,I4,3A2,A2,12I4)

001001  I5 -9999          Experiment ID
002001  I5 -9999          Rat ID
003001  I2 -9             Day of Month
004001  I2 -9             Month
005001  I4 -999           Year
006003  A2 --             Treatment Code
009001  A2 --             Rat Condition
010012  I4 -999           Heart Rate
```

THEORY OF OPERATION

There are usually several DDFs existing simultaneously on the disk for different applications. When a user is preparing to use the IFEMDBS programs, the appropriate DDF must first be copied into the file named CURRNT.DDF. This is the DDF file the IFEMDBS programs will refer to. The CURRNT.DDF file does not then have to be reinitialized until a different DDF is copied into it for some other application. Once CURRNT.DDF is read and analyzed, file manipulation can take place. The general flow chart followed by most of the IFEMDBS programs is shown in Figure 3.

FIGURE 3. GENERAL FLOW CHART



During the reading phase, entries are stored into the 999 word array IRECRD according to the I/O format. Space is allocated by field type. An integer or ascii field takes up one word per entry. The list field is stored one character per word using an A1 format, and requires one word for each character in each of the entries. Figure 4 shows how the IRECRD array will be allocated for the oxygen toxicity records.

PROGRAM DESCRIPTIONS

The IFEMDBS programs share one characteristic: they treat input files as read only. This minimizes the risk of accidental file destruction. The manipulated file becomes the newly created output file. The function of each of the IFEMDBS programs, and the nature of the output file created is shown in Figure 5. The DBS series is the most important group. It allows an input file to be sorted into two different output files, with the disposition of records determined by the entries in a particular field.

FIGURE 4. ARRAY ALLOCATION

ARRAY SPACE	CONTENTS
IRECRD (1)	Experiment ID
IRECRD (2)	Rat ID
IRECRD (3)	Day of month
IRECRD (4)	Month
IRECRD (5)	Year
IRECRD (6-8)	Treatment codes*
IRECRD (9)	Condition code
IRECRD (10-21)	Heart rates*
IRECRD (22-1000)	Unused

*Null values where appropriate.

PROGRAM INTERACTION

It is often desirable to create a data file which requires a more complex search than the simple examples shown in Figure 5. These higher level searches can be accomplished using the output file from one program as the input file to another. Figure 6 illustrates this process on the MASTER.RAT file. In this example, the final

FIGURE 6. COMPLEX SEARCH

FILE CONTENTS	FILE NAME	PROGRAM	RUN DESCRIPTION
All expts.	MASTER.RAT		Search Y= 1970-1979
		DBS2	
All expts. 1970 - 1979	YEARS.RAT		Search T= AA
		DBS1	
Y = 1970-1979 T = AA	TREAT.RAT		Search C=DD
		DBS1	
Y = 1970-1979 T = AA C = DD	DEATH.RAT		Sort on expt. ID field
		DBSH1	
Y = 1970-1979 T = AA C = DD In ascending order by experiment ID.	FINAL.RAT		

Field Abbreviations: C = condition, T = treatment, Y = year. Entry Abbreviations: AA = gas mixture, DD = death before completion.

output file will contain all experiments run between 1970 and 1979 with treatment code AA in which the rat died, and will be in ascending order by experiment ID.

FIGURE 5. THE IFEMDBS PROGRAMS

PROGRAM NAME	PURPOSE	OUTPUT FILE	EXAMPLE
DBNEW	Interacts with user. Create new data file - simplified input procedure.	New data file	Input oxygen toxicity records into NEW.RAT.
DBED1	Change record entries by various editing options.	Identical to input file except for user's changes	change incorrect treatment code in second record.
DBM1	Merge two or more input files.	Records from file #1 followed by records file #2, etc.	merge individual rat files into MASTER.RAT.
DBS1	Search for particular entries in given field.	Records containing that field entry.	prepare file of records with treatment codes AA or BB.
DBS2	Searches for ranges of entries in given field.	Records containing a field entry within the specified range.	prepare file of records with heart rates between 200-250 BPM.
DBS3	Search for record position.	Records within the position ranges.	prepare file of records in 4-6 and 10-15 sequential positions.
DBCH1	Change all occurrences of one entry value to another.	Identical to input file except for changed entries.	change treatment code AA to A1.
DBSH1	Sort file by one or more fields.	Same records - new sequence.	sort MASTER.RAT by experiment date, subsort by experiment ID.
DBD1	Display file in intelligible format.	None	Display the MASTER.RAT File.
DBCRT	Create DDF for new application.	New DDF	Create RAT.DDF.

THE IFEMDBS SUBROUTINE LIBRARY

The library of Fortran callable subroutines is designed to allow easy programming for any IFEMDBS application which cannot be accomplished using the standard programs. These typically include graphic and statistical analysis, or specialized report generation. Examples of some of these subroutines are shown in Figure 7.

FIGURE 7. SOME IFEMDBS SUBROUTINES

SUBROUTINE NAME	PURPOSE
INREC	Read record from previously opened logical unit number.
OUTREC	Output record to previously opened logical unit number.
GTNTRY	For given field, query user for entry. Accept entry in appropriate format for that field.
DELETE	Delete entry from record position and replace with null value.
INSERT	Insert entry into particular record position.
SHOW	Display record contents in "extended format".
ASPECT	For given field, determine various aspects according to DDF. Return values for field type, starting entry. Last entry, field length, null value, and 20 character label.
ENTRY (logical function)	Determine if given entry is in given field.
GETDDF	Read CURRNT.DDF and set up the common/DDB/ area.

BENCHMARK RESULTS

All of the IFEMDBS programs require a certain amount of run time for user interaction. Very little CPU time is used during these interactions. Five of the programs also require a significant amount of time for file manipulation. These are DBM1, which merges data files; the DBS series which searches an input file and prepares an output file of "found" records; and DBSH1 which rearranges an input file.

We investigated the relationship between file length, record length, and number of record matches on the File Manipulation Time (FMT) required by these programs. Our file device was an RK05 disk drive accessed under the RT-11 operating system. The test file had records with three fields. Field one was integer, 4 characters long, and had the record's unique sequence number entered. The second field was a list, with varying entry length, and consisted of a string of ascii characters. The third field was identical in type to the first, but had the reverse sequence numbers entered. This was the field entry on which we tested our sorts.

File length was altered by varying the number of records in the file and the range of sequence numbers while holding record length constant at 26 characters. Record length (characters/record) was altered by changing the entry length of the second field and the appropriate sections of the DDF while holding file length constant at 600 records. The timing of FMT began as soon as user interaction was finished.

Since the DBS series and DMB1 follow a similar algorithm, DBS2 was chosen as a representative example. DBSH1 was investigated separately. In DBS2 an input record is read, examined against a search template and flagged if a hit is found. Flagged records are output to the found file. Non-flagged records can be either discarded or sent to the non-match file. In our benchmark tests, unflagged records were not saved. Thus unflagged records required only a read cycle, while flagged records required both a read and a write.

The effects of file size and record length on the FMT of DBS2 are shown in Figure 8 and 9. Both a "best" and a "worst" case search were examined. In the best case, the search template was designed to produce a hit with none of the records in the file and gives the shortest FMT.

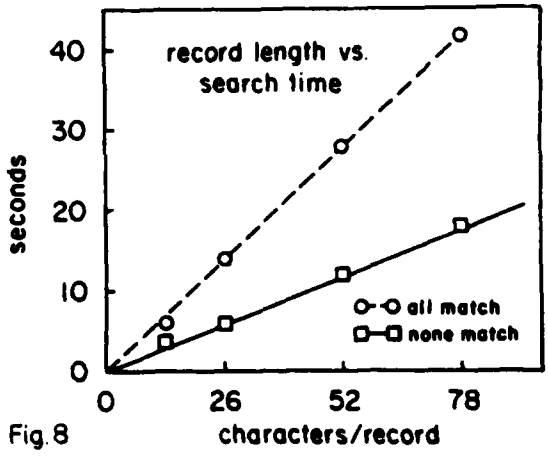


Fig.8

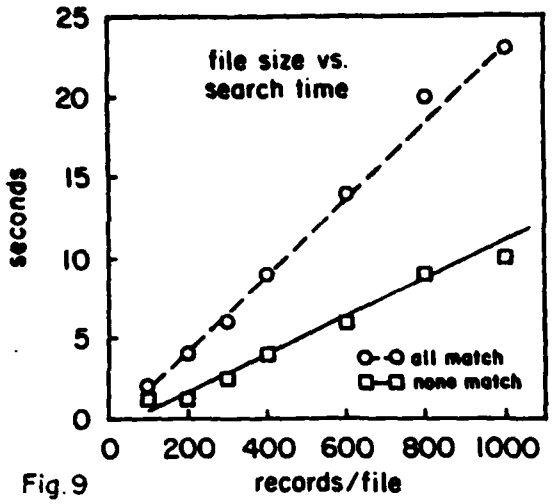


Fig. 9

In the worst case, the template produced hits every time and gives the longest FMT. The File Manipulation Time for DBS2 is dominated by I/O cycles, with almost no contribution from non-I/O CPU time. This is clear from the linear relationships between FMT and file size and between FMT and record length in both the best and worst cases. The FMT dependency on record length further implies that the time required for one I/O cycle is a linear function of the number of characters in the record.

The relationships between the file and record characteristics and the FMT is not as straightforward in the sorting program (DBSH1). The general algorithm for the file manipulation sections of DBSH1 is shown in Figure 10.

FIGURE 10. FLOW CHART FOR DBSH1

1. Interact with user to set up program.
2. Count the number of records in the input file.
3. Open a random access binary scratch file.
4. Translate the input file from sequential ascii to random access binary.
5. Read the sort-entries and record positions from the random access binary file.
6. Perform a bubble sort in memory on the sort entries.
7. If there are more entries to sort, go to step 5.
8. If sorting is finished, translate from random access binary to a sequential ascii output file using the current record positioning.
9. Close files and terminate program.

Most of the FMT comes from steps that are heavily I/O dependent, and this accounts for the overall linearity of the graphs shown in Figure 11. The slight curvature of the line describing FMT vs. file length resulted from the memory bubble sort step in DBSH1, which required no disk I/O but a significant amount of CPU time.

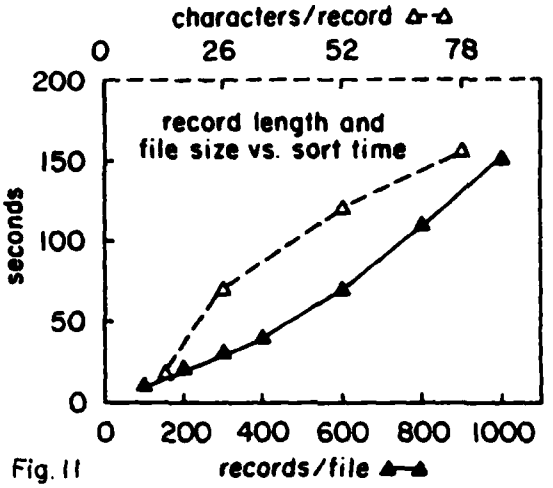


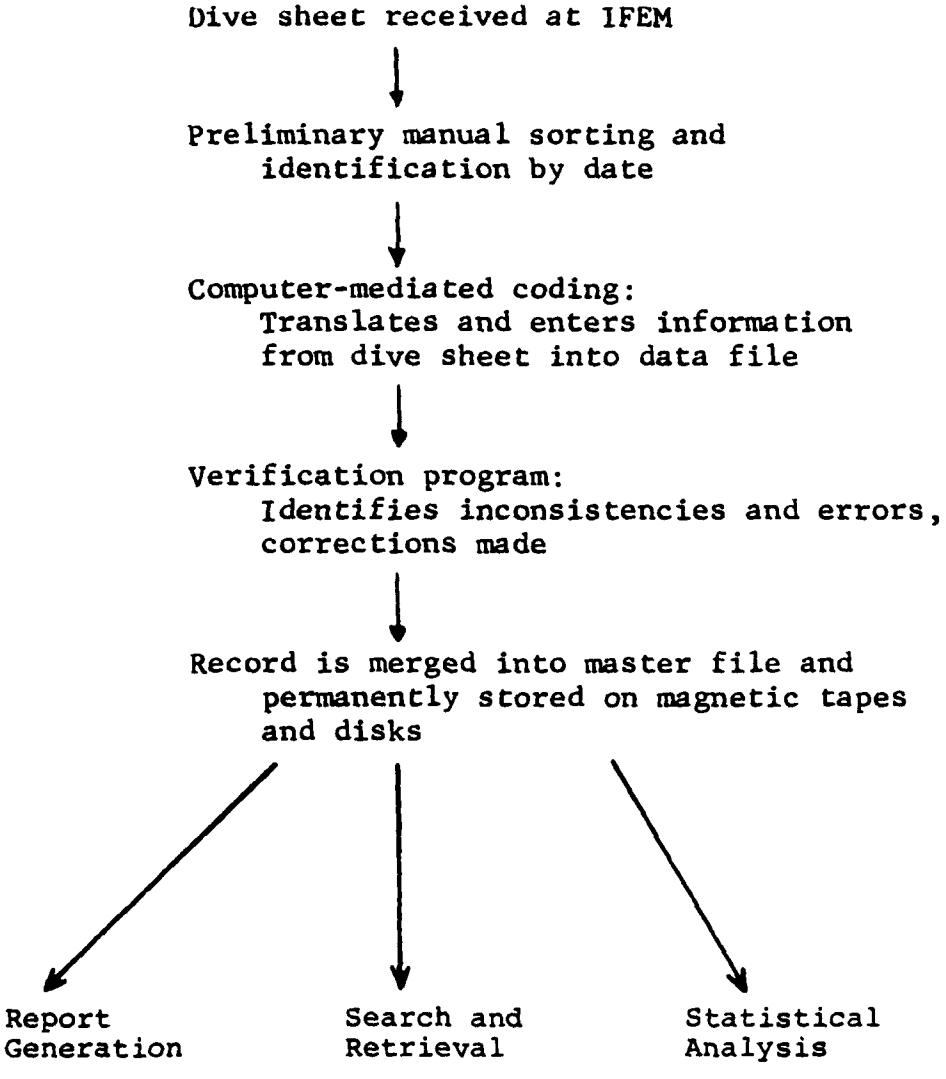
Fig. 11

The sort step is dependent on file size in a non-linear manner. The bubble sort time per record increased with file size. The relationship between FMT and record length is almost a mirror image of the relationship between FMT and file size, with the steepest slope at the smaller record lengths. This is because the bubble sorting time was not affected by record lengths as it was by file size. The sorting step is independent of the record reading step, and operates only on the individual entries.

The sort we investigated required a complete reversal of an input file 600 records long. For this file, 30 to 35 seconds were required for the sorting step for record lengths between 13 and 78 characters. For the shorter records, this 35 seconds accounted for 70% of the FMT. For the longer records, the sorting step accounted for only 20% of the total FMT. the curvature of the FMT vs. record length was due to a decreasing contribution by sorting time with increasing record length.

DIVING INFORMATION MANAGEMENT SYSTEM

Procedure to Process Diving Records



DIVING INFORMATION MANAGEMENT SYSTEM

File Record Characteristics and Information Fields Currently in Use

Dive Identification Number - each dive record is assigned a unique number

Date of dive

Organization responsible for exposure - name and any specific information required

Confidentiality of record - yes or no, which items

Location of dive - geographic area

Characteristics of exposure

- Hypobaric
- Hyperbaric
- Saturation
- Non-Saturation
- Excursion
- Repetitive
- Salt Water
- Fresh Water
- Dive at Altitude
- Observation Bell (1 ata)

Depth - in feet

Bottom time - in minutes

Breathing equipment used by diver

- Scuba (open circuit breathing apparatus)
- Chamber
- Surface Supplied Light Weight Gear
- Surface Supplied Heavy Weight Gear
- Bell - Pressurized
- Bell - Observation

Gases breathed

- Air
- Helium ($He-O_2$)
- Nitrogen (N_2-O_2)
- Neon ($Ne-O_2$)
- Oxygen (100%)

Decompression table

- U.S. Navy Std. Air
- U.S. Navy Air/Surf w/O_2
- U.S. Navy Mixed Gas
- U.S. Navy Air/Surf w/air
- Observ. Bell
- Saturation

Decompression schedule - depth/bottom time

Diver identification number and code to identify crew position

- Diver
- Supervisor
- Regulator Operator
- Control Van Operator
- Tender
- Winch Operator
- Extra Man or Standby
- Life Support Technicians
- Bellman

Purpose of dive

- Equipment Testing
- Experimental
- Medical Treatment
- Sport or Recreation
- Training and Qualification
- Working

Unusual events or diagnosis

- Decompression Sickness, Type I
- Decompression Sickness, Type II
- Suspected Decompression Sickness
- Respiratory Failure
- Hyperventilation
- Hypoxia (Lack of Oxygen)
- CO_2 Toxicity
- Oxygen Toxicity (or other oxygen effect)
- Inert Gas Narcosis (usually nitrogen)
- High Pressure Neurological Syndrome
- Cerebral Gas Embolism
- Barotrauma (squeeze) - Inadequate Pressure Equalization - Usually on Descent
- Compression Arthralgia (joint pain during compression)
- Otic Barotrauma (sinus, ear squeeze)
- Otitis Externa (ear infection)
- Skin Infection
- Exhaustion
- Gas Supply Contamination
- Omitted Decompression

Near Drowning
Hypothermia
Death
Blow-Up
Mechanical Injury (broken bones and sprains)
Breathing Equipment Failure
Other Equipment Malfunction
Entrapment
Injury by Marine Organism

Observed symptoms

Swelling
Headache
Pain, Soreness, Tenderness, or Ache
Itching
Crepitation
Rash
Skin Abnormalities Other Than Itching or Rash
Cyanosis
Tinnitus
Hearing Disturbance Other Than Tinnitus
Vertigo
General Diziness
Ataxia
Restlessness or Anxiety
Malaise
Euphoria
Drowsiness
Unconsciousness or Coma
Nausea
Vomiting
Visual Disturbance
Nystagmus
Muscle Twitching
Numbness
Paralysis
Generalized Weakness
Loss of Reflex
Chill
Diaphoresis
Dyspnea
Apnea
Tightness of Chest
Bleeding
Tremors
Diarrhea
Convulsions
Shock
Paresthesia
Mental Disorientation
Tingling
Chokes

DATE
ILME